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Modelling visual impact of power lines: Does visibility influence health risk perception?

Mihaela Violeta Gheorghe

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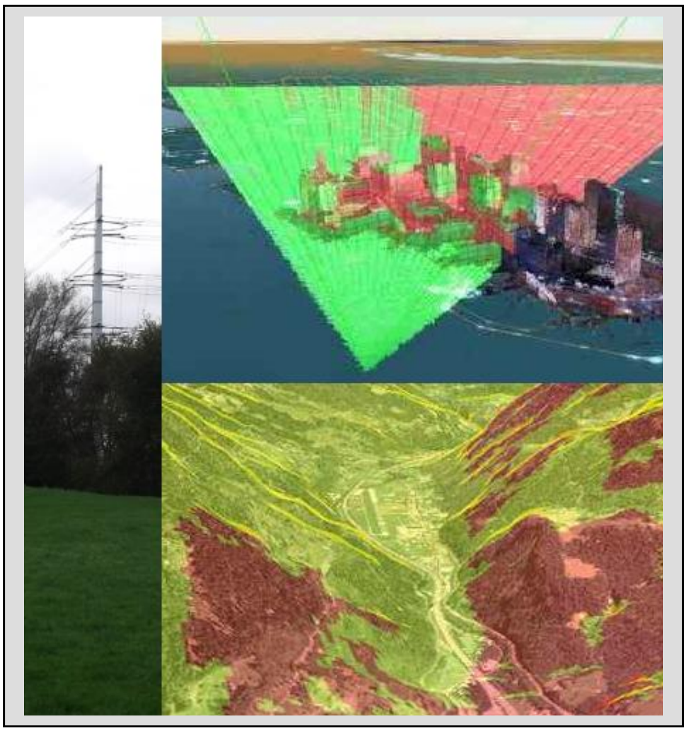

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Modelling visual impact of power lines: Does visibility influence health risk perception?

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Preface

This report is written to fulfill the requirements of Master in Geo-Information Science at Wageningen University. During the sixth period of the first year of my master program at the Wageningen University, I have had the opportunity to get involved in a study that links GIS to psychological aspects of our daily lives. A psychological study had been conducted in a study area from The Netherlands, where power lines were recently reconstructed. The study made available health risk perception values. The requirement was using GIS to derive the relationship between these values and the visibility of the power lines. Because I found the theme very interesting, and the required work proved to be extensive, I decided that it would represent a subject suitable for my thesis work. During the whole process corresponding to the thesis work, I have discovered that visibility studies are currently limited by conventional methods. GIS methods are used to derive visibility in many recent studies, but the concept is still new, and a lot of improvements can be brought to the current analysis.

I consider that the working process helped me improve some of my skills. The need to select information from a large number of previous studies helped me improve my critical thinking and be selective with my sources. Developing a method to answer the proposed research questions required a problem-solving approach. The existence of a study area made it possible for me to enrich the process of my research with a fieldwork survey. Assessing the quality of data and implicitly of the obtained results by measurements, is a very important steps in GIS studies, especially because their main purpose is modeling real world aspects. I consider that working on this subject was an opportunity, from which I could learn

Acknowledgments

First of all, I would like to thank to my supervisors, Ron van Lammeren and Jarry Porsius, for sharing so much time for meetings and extensive feedback on my report. Even though I have chosen to carry the work on my thesis from home, their involvement with the process of supervising helped me keep a very good communication, exclusively online. I have receive valuable hints on how I should continue, or constructive feedback on what I had already done, whenever I have solicited them.

I also thank to my family, who supported me during the whole process. They shared my excitement, but also my worries regarding the progress of my work. The fact that I was at home while working on the project, helped me focus on the work exclusively, and not on the feeling of being homesick.

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Summary

In our daily living environment the perception of high voltage power lines in landscapes could have a serious impact on well-being, their presence being associated with certain burdens, like electromagnetic fields, property value estimates or visual intrusion. The present study focuses on the latter burden, visual intrusion, believed to have an influence on how people perceive health-related risk associated to living nearby power lines. Most of the studies that assess visibility use conventional methods, like photography, questionnaire surveys or expert assessments. Since geo-data has become a commodity and offer detailed information in spatial and temporal sense, a geo-data modeling approach could help understanding the relation between high voltage power lines visibility and human health risk perception. This concept is tested by finding appropriate data sets, developing a clear definition for visibility and a transparent calculation procedure to derive visibility, and link it to personal health concerns.

The procedure of deriving visibility is applied for a study area where levels of health concern related to power lines have already been derived by means of digital questionnaires, in a previous psychological study. The existence of a study area made possible the validation of the obtained results, through fieldwork measurements. The validation results brought into attention the importance of input data quality. Significant discrepancies between used data and reality raise raise questions regarding even the feasibility of the study.

The correlation found between visibility and health risk perception is low. However, the initial hypothesis regarding a possible correlation between the two factors is not entirely dismissed. The possible causes that led to the obtained results are discussed. Considering the possible causes, recommendations are given for future adjustments of the method and correlation analysis.

1 Introduction

Electricity is a necessity of the modern world. Since the beginning of the 20th century, the growing consumption of electricity has created further needs of developing networks at global and national levels, resulting in large-scale effects on the landscape Soini et al. (2011). Electricity is essential for our society, and its distribution has to be made from remote power stations to populated areas. Electricity transmission is performed by networks, which from a hierarchical point of view, consists of high voltage power lines which are found in less populated areas, and lower voltage lines in urban areas Sumper et al. (2010). The continuous expansion of the distribution networks implies the construction of infrastructure facilities sometimes in residential settings, in which case it arises high levels of public concern regarding the potential impacts on the quality of the surrounding environment Priestley and Evans (1996). Even though the landscape around the power lines can be compared to a large-scale infrastructure of production, serving the needs of society, the power lines imply special attention and need for research, because they can be perceived by many as a landscape damage Soini et al. (2011) or even a health threat Chapman and Wutzke (1997). In the early 1990s, the theory about the potential links between electromagnetic fields (EMF) to transmission lines and higher rates of cancer lead to an increased interest in perceptions of transmission lines health effects Priestley and Evans (1996). The research done in the last two decades have not provided a clear evidence to support the adverse health effects caused by exposure to electromagnetic fields (EMFs). On the other hand, no solid proof have been found to contradict the theory Kulkarni and Gandhare (2012). Therefore, there are uncertainties among population concerning the real health effects of EMFs, regardless if they are generated by mobile stations, mobile phones or overhead power linesTseng et al. (2013). Living in the vicinity of this type of structures result in higher interest regarding the impacts that they can have on the surrounding environment Sumper et al. (2010).

2 Problem definition

The way people perceive their environment depends on many factors, such as personality Abello and Bernaldez (1986) education Savage and Kong (1993) and environmental attitudes Kaltenborn and Bjerke (2002) as well as leisure activities in their residential location Brody et al. (2004). Soini et al. (2011) confirmed that these factors can be associated also with the perception of transmission lines. In addition, how people perceive power lines can be linked to whether they consider that living in the proximity of power lines can have an impact on their well-being and their properties. In a review of studies that look at the implications of electricity transmission from power plants to consumers, Doukas et al. (2011) classifies different types of impacts that power lines can have on well-being, by associating them with so called “burdens”. These burdens result in impacts on the residents living nearby Doukas et al. (2011). For example, the presence of the electromagnetic field (EMF) that is known to be found in the vicinity of the power lines could lead to health effects, or worries regarding health risks and property values. The other burden that can affect perception is the visual impact caused by the intrusion of the power lines in the view from a property Doukas et al. (2011). The visual impact of transmission lines is often associated with negative perception of the surrounding environment because they can affect the aesthetics of the landscape and result in a decrease in property values Doukas et al. (2011). On the other hand, power lines can be considered landmarks and serve for orientation if they stand out from the surroundings Priestley and Evans (1996). In conclusion, these two burdens have an influence on residents well-being, by affecting different aspects of their lives: health risk perception, property values or landscape aesthetics.

Some studies link the level of perceived exposure of a potentially harmful object to proximity between the observer and the object Venables et al. (2012); Poortinga et al. (2008). Even though proximity to the proposed objects (in this case a nuclear power plant) have been usually associated with higher concern, studies confirm that the pattern of proximity - health risk perception dependency does not fully apply in cases where higher proximity have been associated with lower concern and greater acceptance Venables et al. (2012). According to the authors, public attitudes seemed to depend more on how the object contributed towards the sense of place of residents, and less on the physical distance between their houses and the power plant. Knowing that physical distance is not necessarily the best predictor for the level of concern towards potentially harmful objects, some studies started looking at other possible predictors of perception, like visibility Priestley and Evans (1996); Pedersen and Larsman (2008), or visual significance López-Rodríguez and Escribano-Bombín (2013). The main assumption in these studies, is that objects found in the landscape surrounding residential areas, are more likely to cause increased awareness among residents if they are more visible. This assumption represent the hypothesis that will be tested in the present study. The hypothesis will be tested by looking at the relationship between visibility of the perceived object, which in our case is represented by power lines, and the level of concern translated here in health risk perception. In this purpose, existent GIS (Geo-Information Science) techniques will be used to implement a clear definition for visibility, in order to provide objective quantification of possible visual intrusion of power lines.

Understanding of perception is considered necessary to manage landscapes as areas "as perceived by people". Understanding what is likely to have a greater influence on what people perceive as being a threat to their well-being, would result in more effective policy-decisions regarding informing population and choosing proper sittings for constructions. For instance, a meaningful relationship found between visibility levels and health risk perception, would result in choosing construction sites from where power lines are less likely to be visible to residents living nearby. In this way, residents would be less disturbed by the presence of power lines in the landscape, and power lines companies would encounter less resistance when trying to extend the power networks. Given that "public perceptions are the basis of an individual's commitments to an organization and its goals and they are major influences on the behavior of both members" Conrad et al. (2011), the findings of this study could result in actions that in the end are beneficial for both people that live near power lines, and for power lines companies.

3 Objective and research questions

The main goal of the current research is defining verifiable quantification indicators of HVPL visibility based on geo-data. Based on the visibility indicators, the study will try to find if there is any meaningful relationship between visibility and health risk perception. Analysis will be performed using a representation of the real world landscape, and will result in numerical values representing an objective quantification of visibility, named "visibility factors". To reach the proposed goal, the following research questions will be answered:

1. What is a suitable definition for visibility and what method is best to use for assessing it using GIS methods?

2. How effective are the calculated visibility factors in representing reality?

3. What is the correlation between the calculated visibility factors and the health risk perception of people living in the vicinity of the power lines?

The following sections of the report are divided into three chapters corresponding to each research question. Chapter 4 describes the methodology applied for finding a definition for visibility and implementing it in a visibility factor analysis processing model . The first part of the chapter, presents a literature review regarding conventional and GIS approaches of depicting visibility. On the basis of the literature review, a definition of visibility is chosen and applied in a GIS work-environment, in order to derive visibility factors. The method applied for answering the second research question is described in chapter 5, "Validation". The chapter details the approach used for validating the quality of the calculated values. Chapter 6, "Results", completes the answers to the first two research questions, by showing the outcomes of the computations for visibility factors, and the validation results. Because of privacy issues, the photos and results displayed in the report don't show information about the exact position of households that responded to the digital questionnaires. A visualization of the results is also available as an appendix, but due to data privacy, it will be made available only on hard copy, to the examiners. The validation process is described in a field work report, which is also handed in exclusively as a hard copy, because of the same considerations. The 7th chapter is linked to the third research question, by looking at the current knowledge about visual impact and perception, and detailing the findings of the studies described in the 4th chapter. In the second part, chapter 7 shows and interprets the correlation results between the calculated visibility factors and health risk

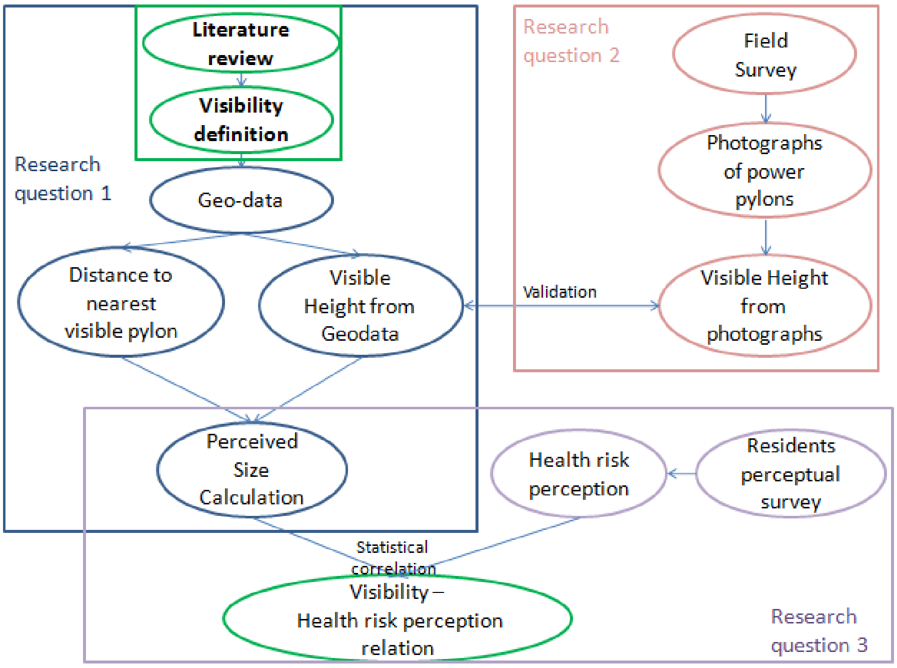

Figure 1: Overview of the paper structure

perception, and therefore answers the last research question. For an overview of the paper's structuring for answering the three research question, see Figure 1. Chapter 8 discusses the answers obtained for each research question, and recommends further approaches for each aspect of the research, from input data, to validation field work and statistical analysis of the results. Chapter 9 ends the paper with a conclusion regarding the findings of the study, and considers the applicability of the proposed method in further visibility studies.

4 Methodology

This chapter answers the first research question. First, it is presented the literature review of ways to describe visibility using different concepts. In order to find the definition of visibility and implement it in a GIS work-flow literature review was done in the following domains: visibility assessment using conventional methods and GIS modeling of visibility. The definition of visibility chosen as the most appropriate for the present study is then used in a processing model to derive "visibility factors".

4.1 General visibility definitions

A popular definition for "visibility" is given by the Oxford dictionary: "the ability to view or the viewing quality of an object or scenery which is affected by atmospheric quality." There are many disciplines that use a totally different meaning for visibility, as for example "the distance of unimpeded visual range" used in aviation or navigation. The present research studies the link between visibility and attitude concerning an object, therefore, it is interesting to consider the psychological meaning of view, which may imply "to understand" or to "perceive" the given object.

Since this paper will focus on assessing visibility using GIS techniques, the term of visibility will be used to refer to an object's status of being "visible" or "invisible", when it is viewed from an observation point. Objects are considered visible according to this definition if the view from an observer to an observed object is not obstructed. Another important aspect of visibility that is explored by this study is "how much can be seen", question that looks at the quantitative aspect of visibility Putra and Yang (2005).

4.2 Literature review regarding conventional methods to assess visual impact on residential areas

The problem of assessing visibility of objects that are found near residential areas have been studied for a long time now. Most of the studies focus on objects that can be visible from a long distance and can have an aesthetic impact on the surroundings: wind farms Bishop (2002, 2003); Möller (2006); Molina-Ruiz et al. (2011), buildings Nijhuis et al. (2011); Hernandez et al. (2004); Rod and van der Meer (2009), mobile phone base stations or power lines López-Rodríguez and Escribano-Bombín (2013); Priestley and Evans (1996); Sumper et al. (2010); Chalmers and Voorvaart (2009); Province (2013).

Priestley and Evans (1996) observed that during interviews conducted in areas near the power lines, respondents reported line or tower visibility that exceeded the judgment of experts. The study described by Priestley and Evans (1996) took place in a residential area where power lines had recently been rebuilt. Questionnaires containing questions referring to the perceived impact of the power lines on the attractiveness of the surrounding area and structure visibility were sent to residents, who answered by rating the impact and the level of visibility on a scale provided by the authors. Subjective values were derived for visibility (1 - only wires visible, 2 - only one or two towers visible, 3 - three or more towers visible) from photography interpretation done by experts. The visibility levels derived on the three-point scale by experts, were then compared to the answers given by residents. Even though residents seemed to overestimate the visibility of the power lines compared to the evaluation done by experts, this factor did not seem to play an important role in influencing perceptions of line effects. As the author explains, the low correlation between visibility and impact might be explained by too little variance in distance, of only 270 m between the properties and the power linesPriestley and Evans (1996).

Another study that makes use of photography to derive visibility of power lines is the one of Chalmers and Voorvaart (2009). Their study uses visibility rates, by coding three views according to three of the most visible structures: "high visibility" corresponds to at least one fully visible arm holding a conductor, "somewhat visible" means that only some portion of the structure is visible, but not a full arm, and "barely visible" describes an entire structure which is obstructed by trees or foliage, but can be recognized. They use the visibility rates to study if seeing the power lines have an important effect on property value. The study reached the conclusion that actually there was a positive correlation between higher property values and visibility towards the power lines. The downside of the study was that only properties on a radius of 150 m from the power lines were considered, therefore higher visibility was a consequence of long views from the property, whose positive effects outweighed the possible negative impact of visibility.

An important study for the present research is the one of López-Rodríguez and Escribano-Bombín (2013). In their paper, the authors try to construct a model to assess the best placement sites for construction of new power lines. They assume that the best placement sites are the ones from where it is less likely for the power lines to impact risk perception of future potential residents. The model must include variables that are likely to affect the risk perception of residents living nearby power lines. However, the research is applied in an area where there is no population yet, therefore, visual/proximity factors are the only ones considered relevant as available variables. They calculated a so called "visual significance" of power lines, using three variables: power line design, critical areas where viewers will concentrate, and zones of visual significance. The power-line design factors were represented by numbers and combinations of different components of power lines, that are likely to affect the observers. Zones of visual significance were defined as the zones that present greater concentrations of potential viewers, and have a direct view of the facility. These variables were weighted by six experts and assigned levels of visual significance. The visual significance was considered by the experts as a potential factor that is likely to influence perception of residents. Since the area in which the study was conducted was not yet occupied by residents, testing this theory with surveys conducted among residents was not possible.

The studies described above use visibility levels based on trained-expert assessment. In the absence of a general definition of visibility, this type of evaluation is considered to have a high degree of subjectivity. The need of a more objective approach to quantify the visual impact of power lines in landscape was met by studies where visibility is derived by calculating objective indicators of visibility, like the vertical visual angle of a visible structure Pedersen and Larsman (2008); Torres Sibille et al. (2009).

In the study of Pedersen and Larsman (2008), visual attitude towards wind turbines is assessed in order to discover what influences most the annoyance experienced by residents living near wind farms. The residents filled in questionnaires containing among others, information regarding their visual attitude towards wind turbines. Their visual attitude was assessed by evaluating the "opinion about wind turbines" related to the impact they might have in the landscape. These measurements were assessed on 5 point scale, ranging from 1 = "very positive", to 5 = "very negative". In addition, the subjects had to agree or disagree with 14 descriptive words for wind turbines, related to aesthetic aspects (beautiful, ugly, natural, unnatural). From these description, new variables were obtained, by associating description of opposite adjectives, like "beautiful-ugly". The variable measuring the "impact on landscape" and the variables obtained from opposite adjectives association were considered as indicators for the visual attitude. The noise annoyance was depicted on a five-point rating scale, where respondents had to specify for a number of possible disturbing factors, inducing wind turbines, whether they find them annoying or not. The scale ranged from 1 = "do not notice", to 5 = "very annoyed". The subjective ratings gave by residents were compared to calculations of the visual vertical angle, expressed in degrees Pedersen and Larsman (2008). The visual angle was calculated for the location of each respondent house, after measuring the distance to the house and the difference in height between an horizontal and an imaginary line from the dwelling of each respondent to the hub of the nearest wind turbine. The nearest turbines was chosen because the closest visible object is most likely to have a greater impact on a viewer. The results of this study show that the annoyance of residents caused by wind turbines was positively associated with the visual angle. In turn, visual attitude was found to be influenced by degrees of visibility of wind turbines: greater visual vertical angles corresponded to a more negative attitude, which results in greater annoyance among respondents.

The conventional methods of assessing environmental impact of visibility are the public preference approach and the expert approach Torres Sibille et al. (2009). The first one relies primarily on subjective judgment of the respondents, while experts use different methods, as depicting the degree of visibility on visibility scales and from photography interpretation. The main deficiency of these methods is the lack of an objective indicator of visual impact. Some studies bring improvements and increase the objectivity of visibility assessment, by using objective measures, like visual angles. Their weakness is represented by the possibility of applying this technique for a limited number of locations while it is important for the view from every property included in a study to be assessed. Therefore, the reviewed studies take into consideration too little variance of distance between respondents and the objects of interest - power lines or wind farms.

4.3 Literature review of GIS visibility modeling

Geo-data has become a commodity and offer more and more detailed information in spatial and temporal sense. The above described definitions for visibility are suitable for GIS applications, because they offer the opportunity to find an objective method to quantify visibility. In order to use them, concepts that

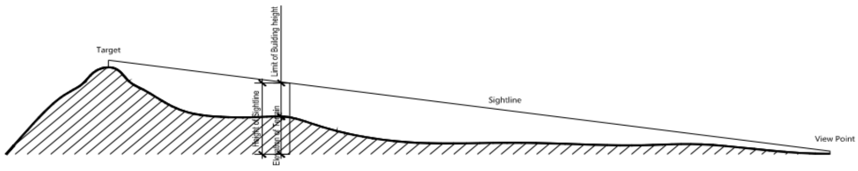

Figure 2: Example of sight line concept
Source: Tong and Ding (2010)

characterize visibility calculations using GIS, are described in the following subsections.

4.3.1 Line of sight, Field of view

In visibility analysis, when defining whether an object is visible or not, the "Line of sight" term is used. A line of sight can be defined as "a straight line that can be constructed to connect the observation point and the target point without being interrupted by any location in between"Tong and Ding (2010) By using a general geometrical definition, visibility depends on the line of sight, or the maximum distance for which the human eye is still able to distinguish particular objects Weitkamp (2010). Therefore, the line of sight concept can be used to implement visibility analysis on a digital elevation model (DEM). When the straight line connecting two objects (in this case the observer and the viewed object) is not blocked by terrain or spatial objects found above it, the points are mutually visible. In the contrary case, the objects will be considered as invisible to each other Liu et al. (2010). In order to introduce the terms used in visibility analysis using GIS, we also define a field of view, as the landscape that can be perceived by an observer from a point, if a complete horizontal rotation and a vertical one from the ground to the sky are considered Morello and Ratti (2009).

4.3.2 Concept of ISOVIST and VIEWSHED

Visibility analysis carried out using GIS applications have consisted so far in two types of analysis. The concepts that are used by these two types of analysis are isovist and viewshedPutra and Yang (2005).

The isovist concept was first mentioned by Tandy in 1967, when it was suggested that its application is to "convey the spatial composition from an observer's point of view". The concept was then mathematically developed by Davis and Benedikt (1979) and has been used ever since, mainly in architecture

Turner (2006); Batty (2001) and urban space studies Yang et al. (2007). According to Morello and Ratti (2009), the concept of an isovist can be defined as “the field of view, available from a specific point of view”. Visibility studies like the ones of Batty (2001), Turner et al. (2001), Fisher-Gewirtzman and Wagner (2003) or Weitkamp (2010), assess space openness and rely on 2D isovists: “the field of view in an horizontal place that represents all the objects that are visible at the same height as the one of the viewer”. Recently, visibility studies like the ones described by Morello and Ratti (2009), Fisher-Gewirtzman and Wagner (2003) or Yang et al. (2007), started focusing on the possibility of using 3D isovists to assess visibility. In comparison to 2D isovists, which consider plans parallel to the ground, 3D isovists are considered more efficient in simulating the physical environment, because they take into consideration perceived volumes in landscape Morello and Ratti (2009). However, at the moment, available software like Depthmap Turner et al. (2001) or Isovist Analyst developed by Rana S., compute 2D isovists, while 3D isovist computation software is still being developed.

While isovists can be considered as “sight field polygons addressing only the horizontal plane”Nijhuis et al. (2011), the GIS-based viewshed analysis is already implemented as a 2.5D concept in GIS software Putra and Yang (2005). Viewshed analysis represents a three-dimensional visibility calculation, based on a surface represented by raster data. The raster data can represent either a Digital Elevation Model (DEM) or a Digital Landscape Model (DLM), which describe earth’s topographical surface Nijhuis et al. (2011). A Digital Elevation Model describes the bare ground surface. Digital Landscape Models represent earth’s surface, but also include the objects found on it, like buildings, infrastructures or land use. The term “viewshed” was introduced by Tandy (1967), as analogy to the watershed. In contrast to isovists, which were mainly used in architecture and urban studies, viewshed analysis was considered a powerful tool for natural resource planners, landscape architects and engineers Ervin and Steinitz (2003). Fisher (1996) and Floriani and Magillo (2003) focused on the technical aspect of the viewshed concept, and therefore, improved the algorithm for calculating visibility on digital surfaces. Even though the raster data model was preferred for viewshed calculations in general, Floriani and Magillo (1994) used triangular-irregular-networks (TINs) to implement visibility analysis.

A main difference between outcomes obtained using the two different types of visibility analysis, isovists and viewsheds, is that isovists generate a continuous bounded area or polygon, while viewsheds are discrete patches, irregular and fragmented Llobera (2003). For isovists, it is possible to calculate parameters that describe geometrical properties, as area, shape or compactness Batty (2001). Instead, studies that use viewsheds refer to the content of found within their area rather than to their geometrical characteristics Miller (2001); Germino et al. (2001).

Figure 3: A typical isovist generated from a viewpoint
Source: Batty (2001)

4.3.3 GIS methods to assess visual impact on residential areas

Visibility analysis using viewsheds and isovists was also used for behavioral and perceptual studies Davis and Benedikt (1979). The researches of Benedikt are among the first ones that looked at the relation between visibility and perception. More recent studies extended the application of isovists to analyze architecture and urban space like galleries, streets or town centers Turner et al. (2001); Batty (2001). Isovists were also developed for visibility graph analysis on TINs Floriani and Magillo (1994). Dalton and Dalton. (2001) developed the OmniVista application for isovist generation, which uses 2D plans describing buildings or roads in urban environments. The research of Dalton and Dalton. (2001) looked at how different characteristics of isovists - area, occlusion, convexity and maximal radial length - can influence the choice for paths made by pedestrians in certain environments, such as art galleries. Another application of the isovists regards characteristics of the perceived landscapes. One of the landscape characteristics that have been investigated using isovists is the openness Weitkamp (2010); Fisher-Gewirtzman et al. (2003).

Ervin and Steinitz (2003) stated that 2D visibility analysis has not provided successful relationships with human perceptual understanding. The study argues that 2D analysis are inconsistent in representing reality, as they are not able to reflect what a viewer would actually perceive. Putra and Yang (2005) analyzed the possibility of using the concept of isovist in GIS-based 3D visibility analysis. He introduced the concept of "viewsphere", which is able to compute spatial properties of residential or urban space based on the volumetric amount of the surrounding space. It is argued that the viewsphere is able to offer a quantification regarding the impact of high-density residential environment on residence's mental geography if interpolated with perceptual indicesPutra and

Yang (2005).

Fisher (1996) brings into attention the potential of viewshed analysis for answering visibility queries in landscape planning. The study questions the suitability of using the viewshed analysis in certain applications, like modeling forest fires visibility or the visual impact of newly constructed objects on the surrounding environment, mainly because GIS users might misunderstand the exact characteristics of this tool, and therefore the obtained output.

The visibility studies that made use of the viewshed concept in their research focus mainly on neighborhood preservation Rios-urban and Chasan (2005); Hernandez et al. (2004), assessment of the visual impact of high buildings on the landscape Nijhuis et al. (2011); Yin and Hastings (2007); Rod and van der Meer (2009), and of recently constructed high objects that might be perceived as dangerous by people: wind farms Molina-Ruiz et al. (2011); Bishop and Miller (2007); Möller (2006) and power lines Province (2013).

Rios-urban and Chasan (2005) and Hernandez et al. (2004) applied the viewshed analysis on assessing the impact of new buildings in the landscape on the existing urban or rural settlements. The study of Rios-urban and Chasan (2005) applies a multi-viewshed analysis in Esri's ArcView software in order to analyze the impacts of changes of buildings heights on certain clusters of neighborhoods. Hernandez et al. (2004) used GISCAD 2.0 to select optimum locations for new rural buildings based on the visual impact the new buildings might have on the already existing residential area. The parameters that were taking into consideration were the scenic composition and background of the viewsheds.

Visibility analysis was also carried out for assessing the values of surrounding views in order to decide on how they influence the values of existing real estate Yu et al. (2005) or the placement of new hotels in certain areas Yin and Hastings (2007). The study of Yu et al. (2005) quantifies views around apartments, to find out whether the height of the surrounding buildings, photography or the height and the orientation of the property itself is reflected in the property's value. Using the same approach of evaluating surrounding views, Yin and Hastings (2007) studies how a hotel could benefit from a good view towards the Niagara Falls. While Yin and Hastings (2007) and Yu et al. (2005) studies mainly the impact of the surrounding landscape on the buildings, researches like the ones described by Rod and van der Meer (2009) and Nijhuis et al. (2011) use viewshed analysis tot asses the visual impact of high buildings on the surrounding landscape. In addition to visibility, Rod and van der Meer (2009) assessed visual dominance, as a measure of how visually dominant the building would be, based on the distance to the building, and how much of it would be visible from observation points.

With the increasing size and number of the wind turbines, the problem of their visual impact on residential areas has drawn the attention of researchers. Therefore, Möller (2006) used GIS to determine the evolution in the visibility of turbines over a period of twenty years and their visual impact on landscapes and population. The same author conducted another wind farm visibility study, aiming to produce quantitative information that could provide a better understanding of the historical development of wind turbines placement in relation to population and land-use distribution Möller (2010). When referring to an object that negatively influences the aesthetics of the surrounding environment, it becomes important that also human perception is studied. Möller (2010) argues that in this case, an outcome that offers information on the possible visibility impact on perception must consist in a composite of viewsheds and population density data in the studied location. The viewsheds show areas where wind turbines are most likely visible, and, by taking into account the distribution of population, identify the residential areas which were more exposed to visual impact through time. The study looks into the past development of wind turbines placement, between 1990 and 2007 It considers that in cases of poor placements of wind farms, a higher number of population is likely to be affected by their visual impact. In the same spirit, of diminishing visual impact of objects perceived as "unaesthetic", Molina-Ruiz et al. (2011) proposes a methodology of applying GIS viewshed analysis to identify best possible locations for new wind farm projects, to prevent or at least decrease the public resistance that is frequently generated in this type of situations.

While it is obvious that GIS analysis have been often used to assess visibility in many different situations, it was not easy to find studies that assess visibility impact of power lines on residential areas. Like the wind turbines, power lines are objects that impact the aesthetics of the environment, and can be perceived as dangerous objects by residents living in their vicinity Priestley and Evans (1996). Recent studies, like the one of Province (2013) describes a viewshed analysis made to assess the impact of a 400kV transmission line that is proposed to be installed along almost 100 km of highways or national roads. The citizens that might be exposed to continue views of the power lines are residents, tourists or travelers. The study offers a way to quantify the level of visual exposure of the proposed power line, based on the distance from them, and the visual absorption capacity of the surrounding objects (the capacity of the surrounding objects - like buildings or vegetation of masking or diminishing the visual impact of power lines). The study was not able to provide any information that links the calculated values to actual human perception of the power lines, because no residents were living yet in the area near the construction site.

Even though Bishop (2002) points out that the perceived visual impact ''remains in the eye of a the beholder'', the GIS visibility tools can offer very valuable information as a basis for further investigations of visual impact. For a better understanding of how objects impact the viewer, objective quantification obtained from GIS analysis can be linked to perception, and interpreted. An accurate replication of the surrounding environment must include information about the terrain's topography, as well as the objects found on terrain's surfaceErvin and Steinitz (2003), but most of the visibility analysis is divided in urban and terrain modeling Llobera (2003). An expanded form of three-dimensional GIS procedure that can integrate terrain and built up environment is needed, but the viewshed analysis in GIS is hardly applied in urban settings, since the raster and TIN data structures are not very supportive for modeling high resolution urban models Llobera (2003). For urban environment which also displays complicated terrain, the visibility analysis may need to cover both the viewsheds and the isovist approaches Yang et al. (2007).

4.4 Literature review conclusion

When comparing to other landscape outstanding objects which can have a negative impact on perception, like wind farms, far less research has been done about health risk perception in relation to living in the proximity of overhead power lines Soini et al. (2011); Limiting et al. (1998); Repacholi and Muc (1999), and even less studies looked at the possible influence of visibility on perceived risk Priestley and Evans (1996). Usually, regardless of the object of concern (wind farms, or overhead power lines), perception ratings are made by residents in the study area, by means of questionnaire-based surveys Kowall et al. (2012); Poortinga et al. (2008); Pedersen and Larsman (2008); Bishop and Miller (2007). These perception ratings are compared to a quantification of visibility, usually obtained by means of lay-men assessment, or to values delivered by experts from photography interpretation Priestley and Evans (1996) and visibility rating on arbitrary scalesChalmers and Voorvaart (2009). Human interpretation of visibility, without considering a clear definition of visibility, delivers results that can be affected by subjectivity.

GIS offers the possibility of eliminating the subjectivity in visibility assessment, if using a clear objective definition and a transparent calculation method that can be performed using geographical data and digital descriptions of the landscape. The reviewed studies that use GIS for visibility assessment apply a viewshed analysis in areas that do not present a high density of buildings. The viewshed analysis offers objective results, by definition it only delivers a "visible" or "not visible" evaluation, in a 2.5 D environment. Firstly, the present research tries to improve visibility evaluation by applying a viewshed analysis in an urban area. Instead of "yes or no" results, a definition of visibility will be chosen and applied in a processing model to obtain quantification of visibility, translated in visibility factors. The definition of visibility will deliver factors that were found to influence perception of people living nearby objects that stand out in the landscape, and can be calculated using geo-data. Proulx (2010) demonstrated that length can capture attention, while Proulx and Green (2011) confirmed that apparent size of tall objects in landscape draw more attention in visual search. Soini et al. (2011) mention in their study that size and appearance of power lines are considered important factors for deriving their visual impact. The definition of visibility will take into account the apparent size of power pylons as the factor that can influence health risk perception. The apparent size will be calculated using existent definitions for "perceived size" Gilinsky (1951); Kaufman et al. (2006). Calculating the perceived size of an object implies determining its height. In order to calculate the portion of the power line that is visible, the proposed method must be applied in a 3D environment instead of a 2.5D one. In their study, Priestley and Evans (1996) considered that an important parameter in assessing visibility is the density of pylons that are visible from each property. Pedersen and Larsman (2008) calculate in their study the visual angle from an observer to the nearest wind turbine. The visibility of the nearest feature is considered to have the greatest influence on a viewer. The results of the study shown that, indeed, the visibility of the nearest wind turbine was related to how people perceive the impact on their well-being. Another study found that visual impact increases with the number of visible objects (in their case wind turbines). Through photography interpretation, they concluded that the visual impact is maximum when wind farm makes up 15% of the view Torres Sibille et al. (2009). Because the proposed implementation of the method allows it, the density of the power line pylons that are visible from each property will also be calculated, for comparison purposes.

The following section will present the definition chosen for visibility and the way calculation was performed. If proven successful, the proposed method would bring an improvement to visibility studies. Unlike conventional methods, the study would give a clear definition of visibility, which depends on measurable variables, like distance and height, by using GIS techniques. Previous GIS visibility studies, use simple viewshed analysis to deliver binary results of "visible" or "not visible", for objects like wind farms, power lines or green houses. The visibility is derived more as a measure of exposure of the objects in question, and never for build-up environments. The results of the studies are zones of visibility, from where possible residents are more likely to see the object in question. The GIS method of deriving visibility using viewshed will be adjusted for applying it in an urban area. Instead of visibility zones that include a number of residents, each household will receive an individual indicator of visibility, called here visibility factor. An improvement of the usual viewshed analysis is that the decay in visibility with increasing distance between the observer and the power lines will be taken into account. In addition, the method will not find only whether the observer sees the power lines or not, but also how large is the visible portion. These considerations take the analysis from a 2.5D environment used in most of the GIS visibility studies to a 3D environment.

4.5 Description of the chosen method for visibility calculation

The main objective is to develop a methodology that can improve the way visual impact of objects in the landscape is assessed with the help of GIS techniques. The methodology would consist in an algorithm that allows an objective quantification of visibility, taking into consideration characteristics that are thought to influence perception. The objective quantification of visibility would be translated in "visibility factors", which are numbers describing to what extent the visual field of predefined locations is affected by visibility of the power line structures. After calculation, in order to be able to draw conclusions regarding on how the visibility affects perception, it will be studied the correlation between the calculated visibility factors and perception values derived from questionnaires in the study area.

4.5.1 Case Study

To develop a sound and reliable visibility analysis tool, the study will be developed for an existent power line. The power line in question is located in a western urban area of the Netherlands, between the municipalities of Wateringen and Zoetermeer. This particular study area was chosen because a psychological study was conducted here, making available results regarding health responses of residents in relation to the HVPL Porsius et al. (2014). The availability of health responses from residents in the area, makes it possible to investigate the relationship between visibility and health risk perception of the power lines, which is lacking in previous power line studies.

The survey conducted in the study area was based on digital questionnaires about health and living environment perception filled in by residents living in the proximity of the Zuidring. The sampling strategy applied for selecting the households participating in the study took into consideration a distance up to 2000 meters from the power lines and a degree of urbanization of maximum 2500 addresses per km^2. One of the indicators for health risk perception is how concerned people are about the effects of the power lines on their personal health. The level of concern in relation to HVPL was assessed with the Modern Health Worries scale, adapted to a list of 11 environmental factors considered by the study. Subjects indicate how concerned they are about the effects of environmental factors on their personal health on a 5-point scale, ranging from (1 = no concern to 5 = extreme concern). The participants also judge on a 5-point scale whether the environmental factors are close or far away from their home. This is considered an indicator for perceived exposure to environmental risk factors Porsius et al. (2014). The concern related to power lines will be compared to the outcome of the visibility assessment, in order to draw conclusion on whether visibility is a good predictor of increased health worries. The relationship between perceived proximity and visibility values will show if more visibility corresponds to feeling more exposed to the effects of the visible object.

From a GIS perspective, the fact that the study area is urban represents a challenge. From what was found in literature, none of the studies that assess visibility using GIS do it for an urban area. They either consider areas with no constructions, or use a less detailed scale of the landscape, losing information about small features like buildings and vegetation, which are very important features in visibility studies. By carrying out the study in this area, a field validation of the reliability of GIS visibility analysis is possible. The recently constructed power line can be found at short distances from homes. The Zuidring consists of three parts: two overhead portions and one underground, The western transmission lines are approximately 4.4 km long from Wateringen till Delft, continue with 10.7 km underground, and ending up with 6.8 km of overhead transmission lines - Zuidring-East in Lansingerland Porsius et al. (2014) (Figure 4).

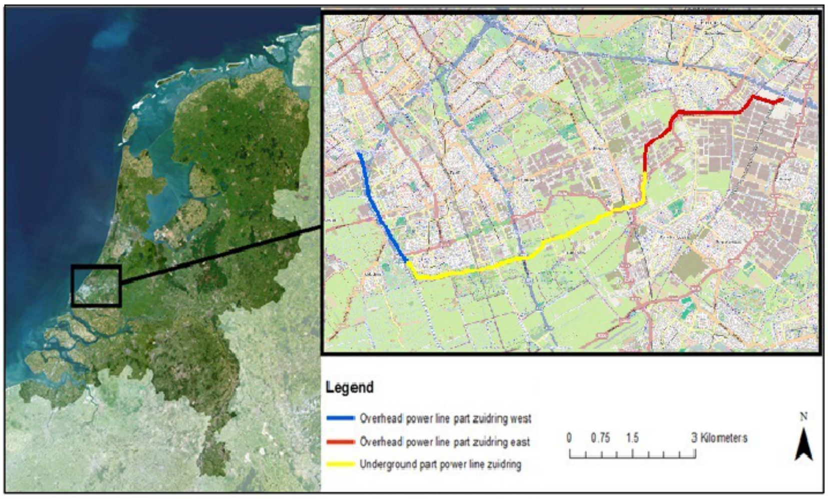

Figure 4: Study area location
Position of the study area in the Netherlands (left); Position of the power lines within the study area (right)

4.5.2 Visibility definition

The viewshed analysis returns the visibility of an object as a binary answer: the object is either visible or not visible, depending on whether the view of the observer is obstructed in the direction of the observed object. But according to the definition, visibility also depends on distance between the observer and the observed object. An object might be visible, but its perceived size, and therefore the impact on the field of view decreases as the distance to the object increases Kaufman et al. (2006). **"The perceived size of an object represents the size of the retinal image created by the eye when looking at the object"** Gilinsky (1951). Perceived size is calculated as a function of perceived distance and the directed angular size of the object Kaufman et al. (2006); Gilinsky (1951):

$$S = d \times tga$$

In the above equation, "S" represents the perceived size of an object, "d" is the perceived distance, and "a" its angular size. The angular size of an object can be calculated if the real size of the object and the length of the line of sight between the eye and the object are known. The perceived distance, named also "apparent distance" is "a direct product of the visual stimulation" Gilinsky (1951). In other words, perceived distance differs from true physical distance, being the subjective distance at which an object appears to be found relative to the position of an observer. In order to calculate the perceived size, firstly, the perceived distance must be known. According to Gilinsky (1951), the perceived distance (d) depends on the physical distance (D) and the maximum limit of perceived distance (A):

$$\frac{d}{D} = \frac{A}{A + D}$$

While the physical distance to an object is easy to determine using GIS computations, the maximum perceived distance is harder to establish, since it is an arbitrary value. If considering the definition given by Gilinsky (1951), (A) can be considered equal to "the visual distance from the observer to the perspective horizon". In this case, we look at the value proposed by Nijhuis et al. (2011) for skyline disturbance value caused by high artifacts, which is of 2000 meters.

By using the definition of perceived size, by knowing the distance to an object, its height and width, we can calculate the perceived height and the perceived width respectively. In this paper, visibility will be considered as **"the area of the retinal image created by the nearest pole for a viewer found on each considered property"**. The apparent area of each object will be calculated using the following definition:

$$S_A = S_H \times S_W$$

where: S_A represents the perceived area, S_H is the perceived height, and S_W is the perceived width. S_H and S_W are calculated using the definition of perceived size, considering the distance between the viewer and a visible power pylon, and the directed vertical and horizontal angular size of the power pylons. The perceived size of the power pylons, and not of the power lines as whole was considered, because the presence of the pylons was found to have a significantly higher negative effect compared to the one of power lines Chalmers and Voorvaart (2009).

The values of perceived size are expressed in square meters and are considered the quantification of visibility calculated using a clear objective approach. If we consider that the magnitude of impact of an object on an observer's view depends on the perceived size of the object Kaufman et al. (2006), than we can use these values further on for answering the last research question, by correlating the obtained quantification with the perceived health risk values derived from the answers in the questionnaire.

4.5.3 Implementation of algorithm in ArcMap and required Geo-Data

To asses the visual impact of the studied power line, the analysis is performed using ArcMap 10.2, extended with Spatial Analyst and 3D Analyst. The analysis consists in standard viewsheds that are calculated on a Digital Landscape Model (DLM), after which the calculations described above are implemented to calculate the visibility factors. Based on a DLM, a viewshed analysis determines which of the surrounding cells can be seen from given observation points in the landscape. Since the study area is a densely populated area, the height of the buildings must also be taken into account. When aiming to return visibility evaluations which are as realistic as possible, the effect of the landscape is also very important. Therefore, in addition to terrain topography and building heights, the trees and hedgerows heights and positions above the terrain elevation must be known.

The quality of the results of a viewshed analysis depends on the quality of the input data Hernandez et al. (2004). The input data used in this analysis is represented by the following data layers:

- a raster data layer representing a Digital Landscape Model the high resolution Actueel Hoogtebestand Nederland (AHN-2, 2007-2012). The AHN data describes the geometry of the study area, with a 0.5 m resolution, and horizontal and vertical errors of centimeters. The AHN is created using LiDAR (Light Detection And Ranging) technology. The raw version of the terrain model contains buildings, vegetation and other features that were found on earth's surface at the moment of its creation. Vegetation, buildings and other features that may obstruct visibility are filtered out after processing the AHN. Even though more accurate, it can be considered that the processed version of the raster data set does not represent the reality this study is interested in. Therefore, the raw version of the digital landscape model will be used as an input. Because the viewshed computations are usually very demanding in terms of computing power, the raster data-set is re-sampled to a 2 m resolution instead of 0.5 m. The raw version of the AHN presents more noise, as it has not been processed yet. Therefore, a focal mean function is applied in order to reduce the noise. Faulty negative and missing values in the DEM were set to zero using a conditional statement.

- vector data shape-files, acquired from a digital topographic map at a scale of 1:5000 (top10NL, 2012). The shape-files are polygon data-sets, holding information about the exact position and shape of buildings, point data set representing the position of the power line pylons, and point data set generated to mark the addresses of the households that responded to the interview. The position of the power line pylons is provided as coordinate by the power company that installed them. The point feature data set contains the coordinates of the power line pylons.

The visibility factor analysis processing model represents a multi-viewshed analysis, and was constructed following guidelines described by the method of calculation used in the study of Rios-urban and Chasan (2005). The steps that are taken in the model are described below (See Figure 5).

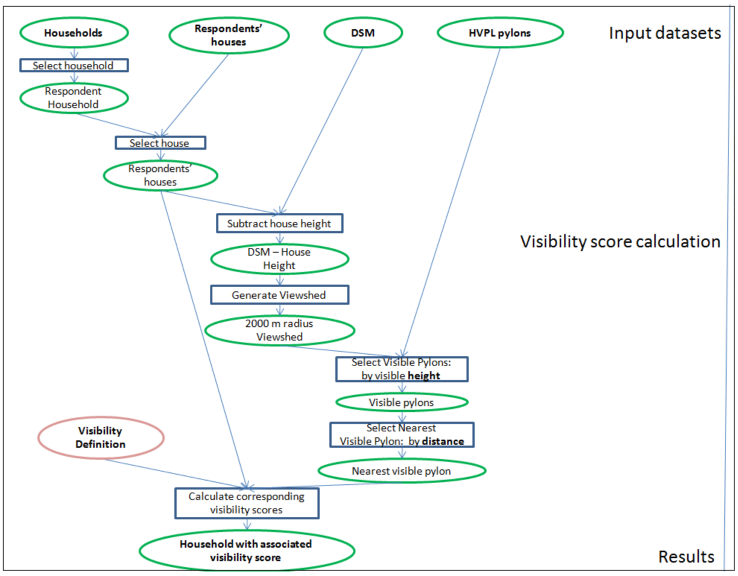

Figure 5: Steps of implementing visibility calculation in ArcGIS

- The viewshed analysis is performed on the DLM resulted from AHN raster data, where cell values represent the elevation of features or terrain;
- First, the household that responded to the interview is selected. The corresponding building is selected through a spatial query and transformed to a raster representing the single building, with the cell values equal to the height of the house;
- The height of the house is subtracted from the whole raster, therefore, at the location of the household's address, instead of the height at the level of the building's roof, we do have the height at the ground-floor level;
- The next step is generating a viewshed which simulates the field of view of an observer would have when staying at the center of the considered building, without considering obstruction caused by this building's walls. The viewsheds generated include azimuth direction from 0 to 360 degrees, and vertical angles from -90 to 90 degrees. The height of the observer (OFFSETB) is set to 1.6 m Weitkamp (2010), being considered the average human eye level. The radius of the viewshed around the observer is set to 2000 m, according to the value proposed by Nijhuis et al. (2011) for skyline disturbance. In addition to the viewshed, the Visibility tool of ArcMAP 10.2 offers the possibility of generating an AGL (Above Ground Level) raster. The cell values of the AGL raster contain the height that should be added to each cell in order for the cell to become visible to the considered observer.

- In order to apply the formula described by Gilinsky (1951) for perceived size, the height of the perceived objects must be known. The average height of the pylons in question is of 60 m. But when viewed from different points, parts of the power line pylons will be obstructed by vegetation or buildings. A visible cell at the ground level will have the value "0" in the AGL raster.

- All visible pylons in radius of 2000 meters are identified with the help of the AGL raster. The AGL cell value at the location of each power pylon will be inquired: if the cell value is between 0 and 60 m, then the power pylon or a part of it is considered visible. The number of visible pylons within the 2000 m radius is stored and represented in the results table, for comparison purposes regarding correlation with visibility factors.

- From all the visible pylons, closest one to the observer is identified and selected. The distance to this pylon is calculated. Knowing the physical distance and the (D) and the maximum limit of perceived distance (A=2000 m), the perceived distance can be calculated according to the above described formula.

- Perceived size is calculated as a function of perceived distance and the vertical and horizontal angular sizes of the object. To calculate the vertical angular size of an object, (tg a) here, the height of the object and the distance between the observer and the object must be known. How much of the object's height is visible is calculated by subtracting from the maximum possible height of the power pylon, 60 m, the cell value of the AGL at the pole's location. Knowing the approximate height of the visible portion of the pole, the angular size of the object can be calculated as the ratio between visible height and distance. The directed horizontal angular size of the object is calculated considering a constant width of the pylon, of 50 centimeters, and the distance between it and the observer.

The resulted value, S, calculated according to the considered definition and attributed to each corresponding household, is considered the quantification of visibility, or the "visibility factor". At the end of each iteration, each respondent to the questionnaire has assigned the corresponding perceived size of the closest visible pole. These values will be correlated with the values of perceived health risk derived from the questionnaires.

5 Validation

Panoramic photography is used by many researchers for visualization and visual impact validationLange (1994); Dykes (2000); Wang (2005); Torres Sibille et al. (2009). Lange (1994) uses real photographs to generate dynamic and static simulation to evaluate the visual impact of expansion of an existing hydroelectric power station in Switzerland. Dykes (2000) use geo-referenced panoramic photographs to represent geographic information in visualization context. In landscape assessment also the validity of panoramic photographs throughout the literature is well documented and is now widely accepted Torres Sibille et al. (2009). Torres Sibille et al. (2009) use maps to identify points from which wind farm could be visible and classify them into classes, and then use panoramic photographs taken at each point, as validation of the chosen classes. The visual impact indicator that is depicted from photography in the mentioned study is the vertical size of the nearest visible wind turbines. Other studies that derive the vertical size of the nearest visible wind turbines through visualization are the ones of Pedersen and Persson Waye (2007) and Pedersen and Larsman (2008). In these studies, the vertical size of the objects are associated to the vertical visual angle, defined as the angle between an horizontal plane and an imaginary line from a respondent's house to the hub of the nearest wind turbine, expressed in degrees. Bishop (2002) derived the size of wind turbines from static photos, by measuring the area and the perimeter of the features. However, in the reviewed studies, photography interpretation is used as the main method for deriving visible height of wind turbines. In this paper, the visible height of the poles will be depicted using photography for validation purposes.

The truthfulness of the calculated visibility factors is assessed by verifying the height of the visible part of the nearest pole, which is an input parameter in the visibility definition. The data gathering for visible height determination took place in November 2013, during a field survey in the western part of the study area. The measured values will help determining the accuracy of GIS-determined values for visible height, related to reality.

5.1 Field survey for validation

Current satellite images of the western study area were acquired from Google Earth. The images contained the location of the respondent households, and were used for orientation during the fieldwork. They also represented a recording medium for the photograph number corresponding to each household (see Figure 6). An itinerary was per-established in order to assure sampling of at least 20% from the total number of households in west. 140 photographs were taken from an approximate height of 1.60 m, in the direction of the power pylons, from the sidewalks next to the selected locations. Viewpoints as variate as possible were chosen, therefore showing visibility versions that range from full obstruction of the field of view in the directions of the power lines to fully visible poles . When more than one poles were visible from a property, the closest one was chosen by measuring the approximate distance to it, using a laser scope. For more detailed information about the sampling and measuring methods, a field report describing the fieldwork. (Note: The fieldwork report will be made available only in hard copy to my examiners, because of privacy issues regarding display of information about the exact locations of respondent households)

Figure 6: Google Earth satellite image of Tanthof-West area
Used as orientation map during field survey, red dot mark the position of the power pole. Dots indicating position of the households were removed from considerations regarding privacy

5.2 Visible height determination using photography

The visible height of the power line is determined using specialized software for photography interpretation - GIMP 2.0. The software allows measuring the number of pixels that represent an object in an image. When knowing the number of pixels the pylon occupies on a vertical line, the distance to the pylon and properties of the camera, the following formula can be applied for determining the real height of the object that appears in the photograph:

.

$$RealHeight(m) = \frac{ObjectHeight(pixels) \times Distance(m) \times SensorHeight(m)}{FocalDistance(m) \times ImageHeight(pixels)}$$

(Source: http://photo.stackexchange.com)

.

In order to determine the accuracy of size determination using the described software, the height of 20 objects of known height contained in 5 photographs was assessed. The obtained accuracy for the proposed validation method is of $\pm 5\%$ from the object's height. At a maximum height of 60 m, the maximum error in height determination is $\pm 3m$.

5.3 Correlation of validation results with calculation results

The visible height of the power pylons assessed individually for each photograph, using the dedicated software and above formula are considered the true values for visible height. These values are written in a table next to the house number corresponding to the image. For the same house, the height value determined from GIS computations is written in the table. The validation of the visibility factors is made by means of calculating Pearson correlation coefficients between the calculated height values and those obtained from validation. The correlation factor will be a measure of the strength and direction of the relationship between the two variables.

6 Results

6.1 Visibility factors calculation

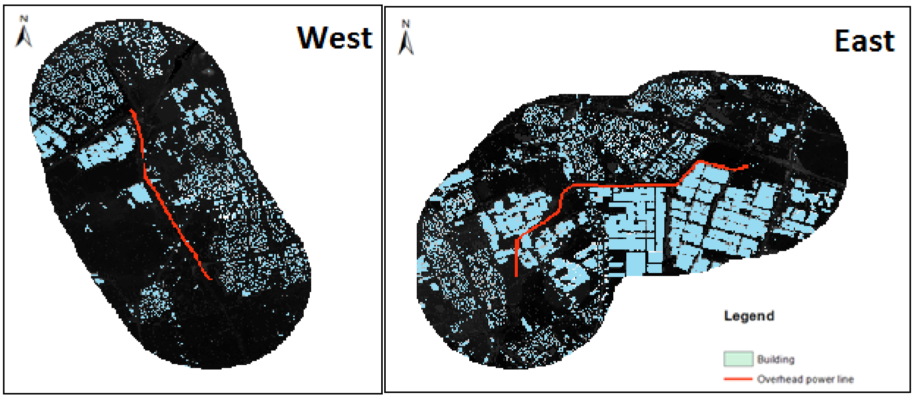

Figure 7: Eastern (left) and western (right) study area
Scale 1:60 000;
Background: Digital Landscape Model

The study area was divided in two zones, each corresponding to a radius of 2500 m from the power lines. The distance of 2500 m was used because the households that responded to the questionnaire are located within a distance of 2000 m from each overhead power line (see Figure7).

Household ID	Pylon Density	Visibility factor (m^2)
1	0	0
2	6	12.7
3	1	13.3
4	2	10.9
5	3	13.9

Table 1: Final results for a subset of five households from the western area

The GIS analysis was run for each of the two areas. The visibility factor has been calculated for 604 households in the western area and 729 households in west. The measure unit for the visibility factors is square meters. The values range from a minimum of 0 square meters, meaning that the household has no visibility toward the power line, to a maximum of 25 square meters for households from which the nearest power line pole is fully visible and close to the viewer. From the total number 604 households, in the western area, 135 houses obtained a visibility score higher than 0. In east, almost half of the households - 349 - were assigned values different from 0. The large difference in the number of houses that can see the power lines within the two areas, can be explained by the different amount of vegetation that can be found in the vicinity of the power lines: in the western area, vegetation masks the power line especially where it can be found very near to the residential area. In east, power lines are not masked by vegetation, but even cross through a built up area. Therefore, less obstruction can be found in east compared to the western area. Minimum values were obtained for houses that have the view in the direction of the power lines totally obstructed by other buildings in front, or they do not have any wall oriented towards the position of power poles. Highest values were obtained for households that are found at a short distance from the power lines - 150 to 200 meters - and to which the nearest pole is fully visible. For the same visible height from a geometrical point of view, houses that are closer received a higher visibility factor than houses found at large distances from the power lines and can see the same portion from poles. The width of the pylons is considered constant, of 0.5 meters, and is used for decreasing the visibility factor as the distance between the household and the power pylons increases.

Table 1 represents a subset of results obtained for five households randomly selected in the western area.

6.2 Validation results

The fieldwork for validation resulted in 129 photographs taken from as many locations. All the photographs were processed using the dedicated software. The values that were obtained for visible height range from 0 m, meaning no visible pylon in the field of view, and 60 m, corresponding to fully visible pylons. From 129 photographs, 51 photos represent positions from where power pylons are visible. The rest of 78 photos were taken from house locations that have no visibility towards the power lines. The field of view from the houses is mainly totally obstructed by other houses in densely populated areas, but there are also cases where even though the power line is found at a short distance from the house's location, the view in its direction is totally obstructed by vegetation. Even though in some cases small portions of the pylons can be seen through, the vegetation is considered opaque, and only the portion of the pole that can be seen above it is taken into consideration. The height values derived from field measurements and processed with photography software, are considered the true values. The height values calculated using geo-data are the values that needed to be tested.

Using a Pearson correlation, a coefficient of 0.70 between the values resulted from validation and the calculated values. When fitting a regression line (see Figure 9), the dependency between the two data sets appears to be linear. Highest correlation was found between the values derived for houses whose field of view is obstructed by other buildings, and not by vegetation. The differences between true values and calculated values have a mean of -2.0 m and a standard deviation of 9.8 m. The negative value of the mean shows that, in general, calculated height tend to overestimate height in comparison to the height derived from photographs. The same trend can be observed in the plots below, after removing the outliers (see Figure 8). The differences that were classified as outliers are at least two times higher than the found standard deviation. The possible reason why the calculated values overestimate visibility can be the changes that occurred in landscape in terms of vegetation. The digital terrain model represents the reality at the moment when the measurements for its realization were acquired. The realization period for the model was between 2007 and 2012. The field survey for validation was carried out in 2013. Growth of vegetation might have occurred in between, masking a larger portion of the visible poles, which resulted in lower height values derived from photographs in comparison to the calculated values. Also, LiDAR measurements could have been acquired in a different season than the measurements for validation. Most likely, to acquire accurate information about terrain topography, LiDAR measurements were taken during winter, when the vegetation cover was reduced.

The correlation coefficient shows a strong correspondence between the results. Still, a series of outliers were identified by considering the standard deviation of 9.8 m. As an example, from the 129 results, in 5 cases, differences of approximately 55 m were found between the validation values and the calculated ones. The visible height derived from validation was of 0, the visibility of the poles being totally obstructed by buildings in front, while the GIS computations returned values corresponding to full visibility of the nearest pole. The digital landscape model was investigated at the location where the large differences occurred. In this area, the digital landscape model presented heights equal to the ground level instead of heights normally corresponding to buildings. By visualizing historical satellite imagery of the same area, it was found that a subset of 19 respondent household currently live in houses that were built after the realization of the digital landscape, and therefore, they are not represented in the model. Photographs between 2009 and 2011 show a free construction site, buildings appearing only after 2012 (see Figure 10). After removing the identified outliers, a new correlation coefficient of 0.93 and a mean of -2.2 m and a standard deviation of 5.4 m were derived from the statistical analysis.

The validation process included 129 households, which represents approximately 10% of the total number of households for which the visibility factors were calculated. A high correlation coefficient was obtained between the validation data set and the calculated values. Even so, the disagreement between the real landscape and its representation in the digital terrain model raises questions regarding the quality of the input data for this type of studies.

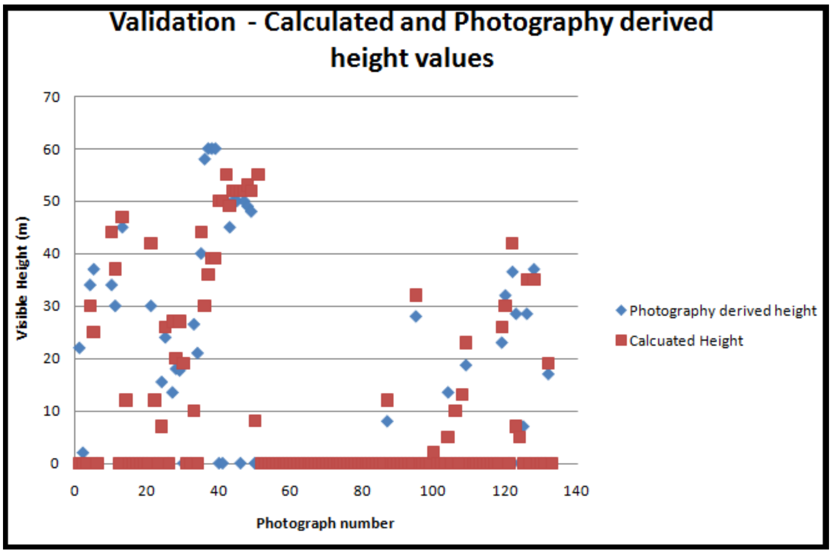

Figure 8: Graphical representation of the photography derived and calculated values for visible height

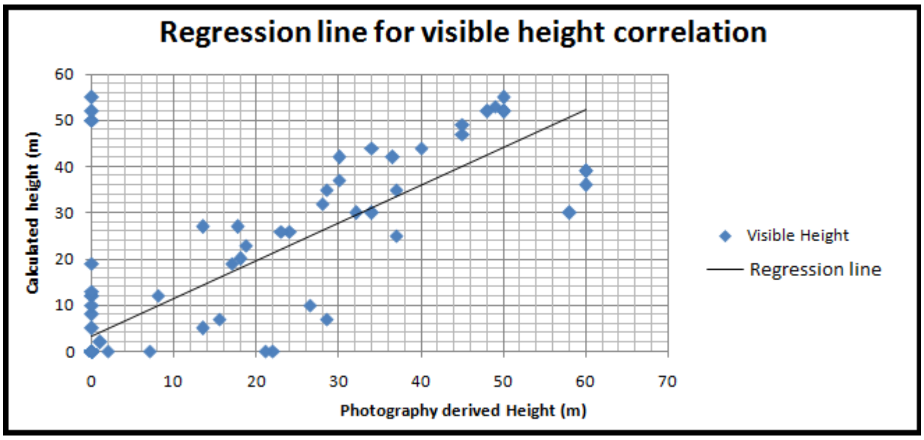

Figure 9: Representation of the regression line describing the correlation between the photography derived height and calculated height

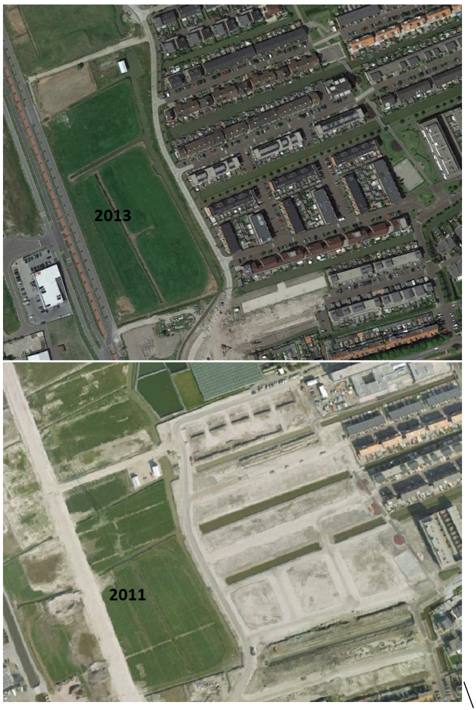

Figure 10: Example of changes that occurred in the landscape

7 Correlation of visibility factors and health risk perception

7.1 Considerations regarding visual impact on health risk perception

The third research question of the present study aimed to verify the hypothesis that an the health risk perception of power lines is possibly influenced by visual factors. Concerns about health risk and safety are considered to depend on thoughts, beliefs and constructs, but also on external stimuli, like physical proximity and visibility López-Rodríguez and Escribano-Bombín (2013). Visibility of a power line means that it can be seen. The fact that it may have a significant visual impact on residents can be more translated as a visual significance Priestley and Evans (1996). The visibility factors that were derived represent a quantification using geographical information, therefore, they only give information of how large the visible structures appear in the field of view. The visibility calculated by this study represents only a variable that can influence visual significance. In turn, if an object is visually significant, depends on many other variables, like contrast against background and atmospheric effects Bishop (2002); Bishop and Miller (2007), distance between the viewer and the object Priestley and Evans (1996); López-Rodríguez and Escribano-Bombín (2013), object size Torres Sibille et al. (2009); Bishop (2002), paint color, number of visible objects, and even how often, how long and where people see the objects. Not all these variables could be taken into consideration in the calculation of visibility factors, because the present study looks only at how geographical information can be used to derive visibility, using a clear definition and a transparent method. The variable that defines visibility in this case is the perceived size of the nearest visible pole from the field of view of a potential observer. Visibility factors are calculated by considering geographical information like distance between the observer and the nearest visible pylon, and height of visible pylons. Knowing that only these variables relating to visual significance of the power line were taken into account, it is expected that the perceived health risk to be only partially predicted. The main assumption is that the more visually intruding a power line is, the stronger the awareness becomes, and therefore, greater the sense of a threat to health is perceived.

7.2 Correlation between visibility factors and health risk perception

In order to verify the hypothesis that health risk perception is correlated to visibility, the relationship between health worries, perceived proximity and visibility factors will be investigated. In addition, for comparison purposes, the analysis will depict also the correlation factor between variables that might influence visibility and were not included in the visibility definition: density of visible power poles. From the problem definition, we could see that many studies associated perceived risk with actual proximity. Correlation results between health concern, perceived proximity and physical distance were also provided, so they can be compared to the relationship obtained for visibility factors. The values of health concern and perceived proximity were derived from digital surveys conducted in the study area by Porsius et al. (2014). Because of privacy issues, the authors could not provide the exact derived values, but only the correlation between them and calculated visibility factors, and the density of the visible pylons.

The values for health worries and perceived proximity were derived on 5-point scales from responses to digital questionnaires. None of the predictors are normally distributed, and the perceived proximity and perceived proximity are depicted on ordinal scales. Spearman's rho correlation is considered to better fit the analysis.

7.3 Results

First, to establish the presence of a visibility effect, a partial correlation was conducted between the perceived risks and visibility factors. Here, it was expected that an increased perceived health risk would be observed for higher values of visibility factors. The expected positive association was found ($R_{Spearman}=$ 0.158; $p < 0.01$). A zero-order correlation shows that there is a small but significant correlation between the two variables. The visibility effect on perceived proximity seems to be a little higher than on perceived health risk, with a correlation factor of ($R_{Spearman}=$ 0.260; $p < 0.01$). The Spearman correlation value between the density of visible power poles and perceived health risk was lower than any other correlation results ($R_{Spearman}=$ 0.126; $p < 0.01$).

Although significant, the correlation values that characterize the relationship between visibility, perceived exposure and perceived proximity are still low compared to the ones that establish the effect of physical distance. The correlation between perceived health risk and physical distance is fair ($R_{Spearman}=$ -0.314; $p < 0.01$). Perceived proximity and physical distance seem to be even more strongly related ($R_{Spearman}=$ -0.555; $p < 0.01$). The relationships that relate power line health worries and perceived proximity to physical distance are more significant than the ones related to visibility. (for all correlation results, see Table 2).

8 Discussion and recommendations

This chapter discusses the practical and theoretical implications of the used methodology for visibility calculation, validation, and obtained results.

The study had three main aims, translated into research questions. The first one was to find a clear objective definition for visibility, which can be assessed by means of GIS. Through an extensive literature research, which looked at conventional and GIS methods to derive visibility, perceived size of the power pylons was considered the most important indicator which characterizes visibil-

	density	perceived size	physical distance	health worries	perceived proximity
	$R_{Spearman}$	$R_{Spearman}$	$R_{Spearman}$	$R_{Spearman}$	$R_{Spearman}$
density	1	.964	.-355	.126	.238
Sig. (2-tailed)		.000	.000	.000	.000
N	1267	1267	1267	955	956
perceived size	.964	1	-.395	.158	.260
Sig. (2-tailed)	.000		.000	.000	.000
N	1267	1267	1267	955	956
physical distance	-.355	-.395	1	-.314	-.555
Sig. (2-tailed)	.000	.000		.000	.000
N	1267	1267	1360	1023	1025
health worries	.126	.158	-.314	1	.374
Sig. (2-tailed)	.000	.000	.000		.000
N	955	955	1023	1023	1023
perceived proximity	.238	.260	-.555	.374	1
Sig. (2-tailed)	.000	.000	.000	.000	
N	956	956	1025	1023	1025

Table 2: Correlation results between perceived health risk, perceived proximity and visibility indicators

ity and can be calculated from geographical data. By using a digital landscape model, the height of the nearest visible was calculated. In addition, the physical distance between the observer and the pylon was derived. These two variables helped determining the perceived size of the nearest pylon according to the given objective visibility definition. This is a transparent method for quantifying visibility by taking into account variables that are easily deduced from geographical data. Unlike other GIS studies, the results returned by the proposed method do not return only "visible" or "not visible" values, but it calculates actual values of visibility. The study of Priestley and Evans (1996), draws the attention on the difference between visibility and what is called "visual significance". Visual significance of power lines may offer a more realistic estimate of how human perceive them. The variables that contribute to visual significance are related to elements that can not be calculated using GIS: preferences for design factors of the power lines, atmospheric conditions, color, contrast, etc Möller (2010); Priestley and Evans (1996); López-Rodríguez and Escribano-Bombín (2013). The proposed method can only contribute to deriving visual significance of power lines, but can not define it entirely. However, the improvements brought by the present study to the current methods of visibility assessment using GIS, are:

- simulating the loss of visual resolution with distance, which is not possible in a simple viewshed analysis;
- taking into account the height of vegetation and other features like houses and fences on land's surface, which gives a more realistic approximation of the generated viewshedsRogge et al. (2008); Sander and Manson (2007). This approach is mainly important for visibility studies in urban areas;
- calculating individual visibility levels corresponding to each household location taking into account individual fields of view, instead of visibility zones;

A critical remark regarding the visibility definition given and implemented by the study, is that it takes into account only the nearest visible pole. This method can prove to be inefficient in some cases. For example, if there are two houses located one next to each other, and they can see the same portion of the nearest power pole, they will receive approximately the same visibility factor (assuming that distance between each of the houses and the pole is not identical). If from one of the houses, there are additional poles visible, their influence will not be taken into account. An improved version of the visibility analysis would consider the perceived size of all visible poles. The visibility factor would result calculated in this case from summing up the perceived sizes of all visible poles in a field of view.

The second aim of the study, defined by the second research question, was to validate the calculated visibility factors. The validation consisted in measuring and then calculating the visible height of the nearest power pylons using photography, and compare it with the values derived from GIS computations for the same measure. The validation campaign did not only offer information regarding the accuracy of the used method, but also about the quality of the input data. These two aspects are very important, because they determine the uncertainty of the obtained results Möller (2010).

The most important findings of the validation are related to the quality of the input data. By analyzing the differences that occurred between the photography derived height values and the ones calculated using the digital representation of the landscape, a series of weaknesses of the DLM were emphasized. First of all, a drawback in the viewshed analysis was that the degree of transparency of vegetation cannot be taken into consideration. According to their digital representation, all the plantations are considered completely opaque.This corresponds to a summer season situation, but it is less accurate for seasons when the leaf cover of trees is diminished or absent. In addition, the resolution of the raster data set had to be diminished from 0.5 m to 2 m. This might have caused a smoothing effect of the vegetation, and a decrease in its overall height. The calculated resulted values tend to over-estimate the visible height, because the obstruction caused by vegetation is reduced.

A second drawback in using the available DLM was that a compromise had to be made between working with the two types of available AHN data. Processed and corrected AHN data did not include information about vegetation height or buildings heights. The raw AHN data was not processed to remove all potential errors, but contains information about vegetation and buildings locations, as well as their height. The raw AHN data was used, since the features on land surface are considered critical in visibility studies. The raw AHN data had to be smoothed out by means of a focal mean function. Even though corrected of noise using this function, the raw AHN does not reach the same vertical and horizontal accuracy as the processed AHN.

The last and possibly also the most important drawback of GIS modeling of visibility is the actuality of the input data. Large discrepancies between some of the validation results when compared to GIS derived ones, led to a further investigation of the landscape model. At least one area that does not represent the current situation from the terrain was identified. By looking at historical satellite imagery of the problematic area, it was found that some of the households that responded to the digital questionnaire lived in houses that were not built yet at the moment when the measurements for the AHN data were taken. The LiDAR measurements for determining the surface characteristics were acquired and updated between 2007-2012. Any change in the landscape that occurred from the last update of the model is not represented. This can lead to high inaccuracies of the obtained results in representing reality. In dynamic areas, frequent and significant changes in vegetation and buildings height and distribution can occur. Large changes in vegetation cover take place even from a season from another, and not all seasons can be considered in a digital model. Updating the digital elevation model frequently implies numerous field surveys, which are time consuming and money costly. Therefore, errors that can occur in the representation of the data, and can not be corrected, put in question even the feasibility of applying GIS methods to derive visibility in built up environments, at a fine resolution scale.

In GIS analysis, in order to get accurate results, it is necessary to use digital geographic information without significant errors. Also, the data must be updated recently enough to meet the purpose of the study. If creating your own data is not possible, before performing analysis, it is recommended to assess the quality of the input geo-data. If necessary, the geo-data must also be updated, or corrected, by means of field measurements to derive height and location information of buildings and vegetation. The work required for correcting a digital landscape model can prove to be laborious and money costly. However, information about height and location of features above ground can significantly affect the accuracy of the generated viewshed, Sander and Manson (2007). Therefore, the information is mandatory for visibility studies performed at fine scales, where the position of individual buildings is taken into account.

The aim of the third research question was to find the relationship between perceived health risk and visibility of the power lines. From literature, it was found the importance of differentiating "visual significance" from "visibility". Even though visibility can be calculated using objective variables derived from GIS data, it has to be kept in mind that it is impossible to predict entirely the visual impact that an object will have on its viewer only by means of geometrical and geographical considerations. In order to get more meaningful results related to perception, a GIS visibility analysis should be part of a broader visual impact study, that includes besides objective visibility calculations, analysis of the natural and built up environment and photographs Rogge et al. (2008). For example, with the help of photography, the level of contrast of the power lines against the background in different atmospheric conditions could be derived by lay-men or experts. Depending on the color of the poles and wires, the clarity of the atmosphere and the type of landscape surrounding them (flat, hills, vegetation), the visibility of power lines could differ significantly from a season to another, and even from a day to another. Levels of contrast derived on arbitrary scales, in association with objective visibility factors are more likely to describe the visual significance that objects have for potential viewers. Talking about potential observers, it is also important to have in mind that the human factor is very difficult to model. While residents might accept the power lines as part of their daily landscape, visitors could find them as intruding objects and experience more awareness related to these environmental factors. As it can be observed, there are plenty of variables that influence visual significance, among which objective visibility. To be able to calculate a better predictor for health risk perceptions, all these variables should be introduced in a model.

If taking into account only a small contribution of visibility in the visual impact of the power lines, despite the small correlation factor that were obtained between visibility and perceived proximity and between visibility and perceived health risk, the results do not cancel entirely the initial hypothesis. However, it must be visibility factors, health risk perception and perceived proximity all relate to a common variable: physical distance. In this case, distance might act as a hidden factor on the found relationships. If known, a way to control for this factor's influence is applying a regression analysis.This approach would be necessary also in a model that includes more than one variable to be linked with perception. By using a multi-level regression analysis, the relationship between each variable and the health risk perception would be described, without the hidden factors among the variables influencing the correlation results.

9 Conclusion

The present research can be regarded as a feasibility study at first. It evaluates the possibility of enriching the current state of viewshed analysis. First, a clear definition for visibility that can be applied in a GIS environment, is chosen through a literature review looking at existent conventional and GIS methods. The definition for visibility takes into account two measurable variables: distance and the height of the power poles. A transparent method is used for implementing the visibility definition in a GIS analysis. The initial improvements that the study intended to bring to the current visibility assessment, were taking into account visibility decay with distance, fine resolution scales for buildings and vegetation representation, and generation of individual values of visibility for each considered location. Because all these initial goals were met, the method proves to have potential in improving visibility studies in urban areas. Outcomes of a validation campaign in the study, to assess the quality of the calculated results and implicitly of the input data, questions the applicability of the method and the possibility of obtaining accurate results. Large discrepancies found between values obtained through field measurements and calculated results pointed to the quality of the digital land surface. Inaccuracies in representing vegetation height, led to an over-estimation of the visibility factors. Missing data about latest updates in the landscape, like new buildings that obstruct the view, resulted in faulty values that affect the statistical analysis that links them to health risk perception. Removing the faulty values from the final results is not possible without a field validation to identify outliers. In this situation, the results of the statistical analysis that links them with health risk perception might be compromised.

The relationship between visibility and health risk perception was characterized by a low correlation factor. A possible conclusion is that higher visibility of power lines does not necessary generate increased health concern among residents living in their vicinity. This conclusion is in accordance with some of the reviewed studies that looked at the visual impact of power lines on human perception Priestley and Evans (1996); Chalmers and Voorvaart (2009); Franc and Rosiers (2002). However, like the mentioned studies agree, the obtained correlation results do not dismiss the hypothesis entirely. It is suggested that a more meaningful relationship might be derived when considering the impact of visual significance instead of simply visibility. Furthermore, replacing the simple correlation analysis with a multi-regression analysis can correct from the effect of hidden factors, and take into account the effect of more than one variables at a time. As Chalmers and Voorvaart (2009) explain, there can be relationships among variables, like for example distance and visibility, and if each is not considered, the effects of one could be mistakenly attributed to another. And the last, but not least, it is known that the analysis included faulty visibility factors, obtained on a digital landscape model that does not entirely represent the reality from the terrain at the moment of evaluating health risk perception.

In conclusion, the present research does not necessary offer a final solution, but rather prove that the current visibility studies left enough place for improvement, and it offers a possible approach for doing that. Some drawbacks regarding mainly the quality of input data, were encountered in the process of deriving visibility using GIS. Otherwise, if using updated geo-data without significant errors, the proposed visibility evaluation methodology is transparent, and able to offer an "objective reference in an often emotionally loaded situation of perceived visual impact" Molina-Ruiz et al. (2011).

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